Modeling of Nioghalvfjerdsfjorden (79 North glacier)

using inverse control methods and higher order formulations

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Acknowledgement to Niels Reeh

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Outline

1. Motivations
   - 79 North glacier, North East Greenland
   - Available datasets (thickness, velocities,…)
   - Flux divergence
2. Effect of a 3d velocity 79 North glacier
   - Control methods on three ice flow models
   - Flux divergence analysis
3. Effect of the thickness resolution
   - 1 km vs. 5 km resolution
   - Do we need a higher resolution?
4. Conclusion

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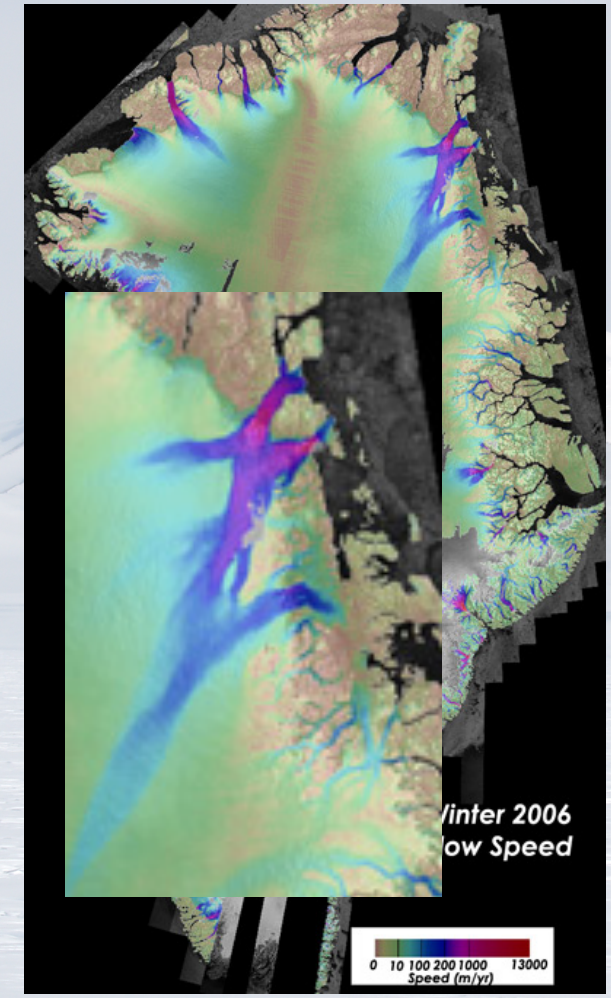
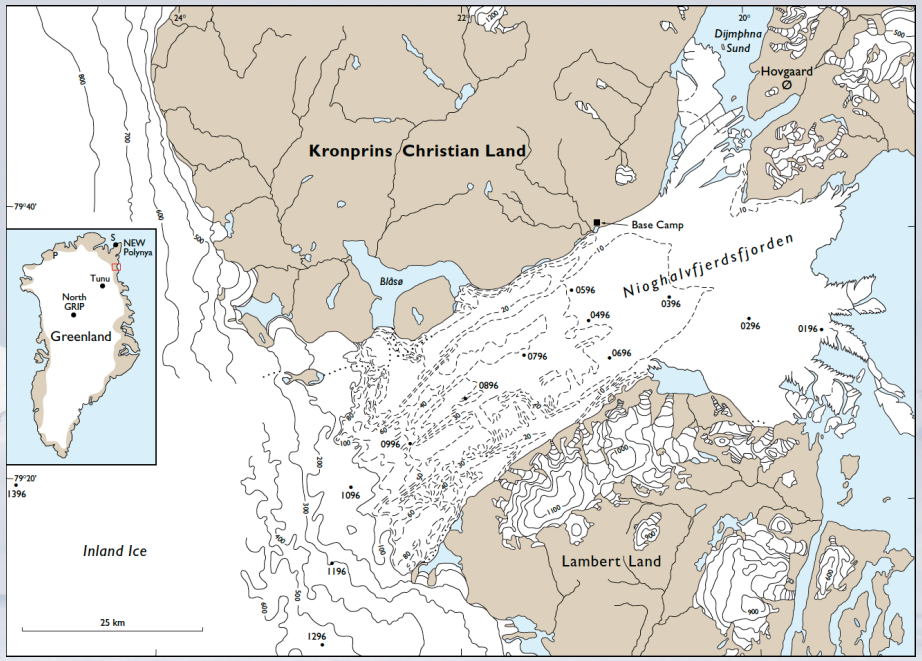
Nioghalvfjerdsfjorden (79N glacier)



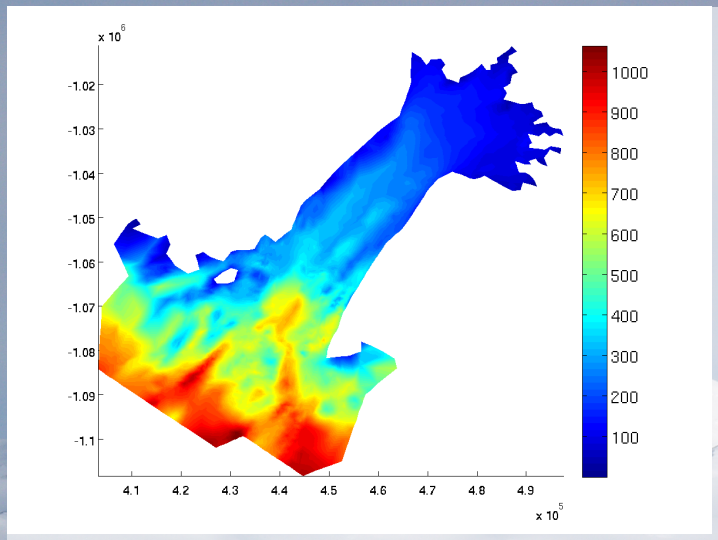
Joughin, 2007



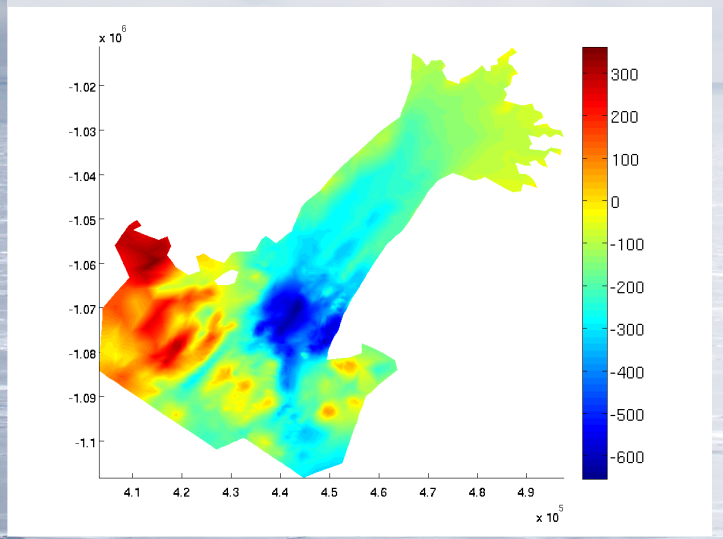
Thomsen, 1997

- Outlet glacier of the Northeast Greenland ice stream
- Thinning at the GL: 0.3 m/yr, Thomas et al, 2009

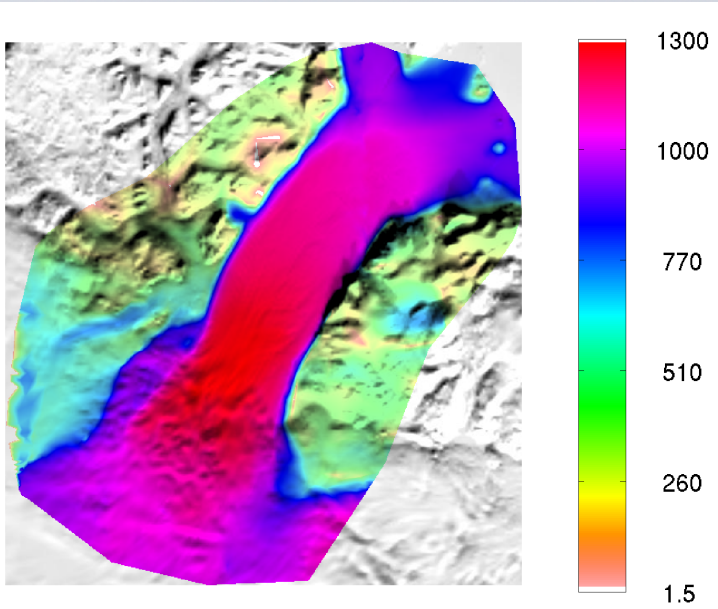
Available datasets



Thickness (m)



Bed topography (m)



Surface velocities (m/yr)

- Bed and thickness, Reeh, pers. comm., 2009
- Velocity, Rignot et al, 2001

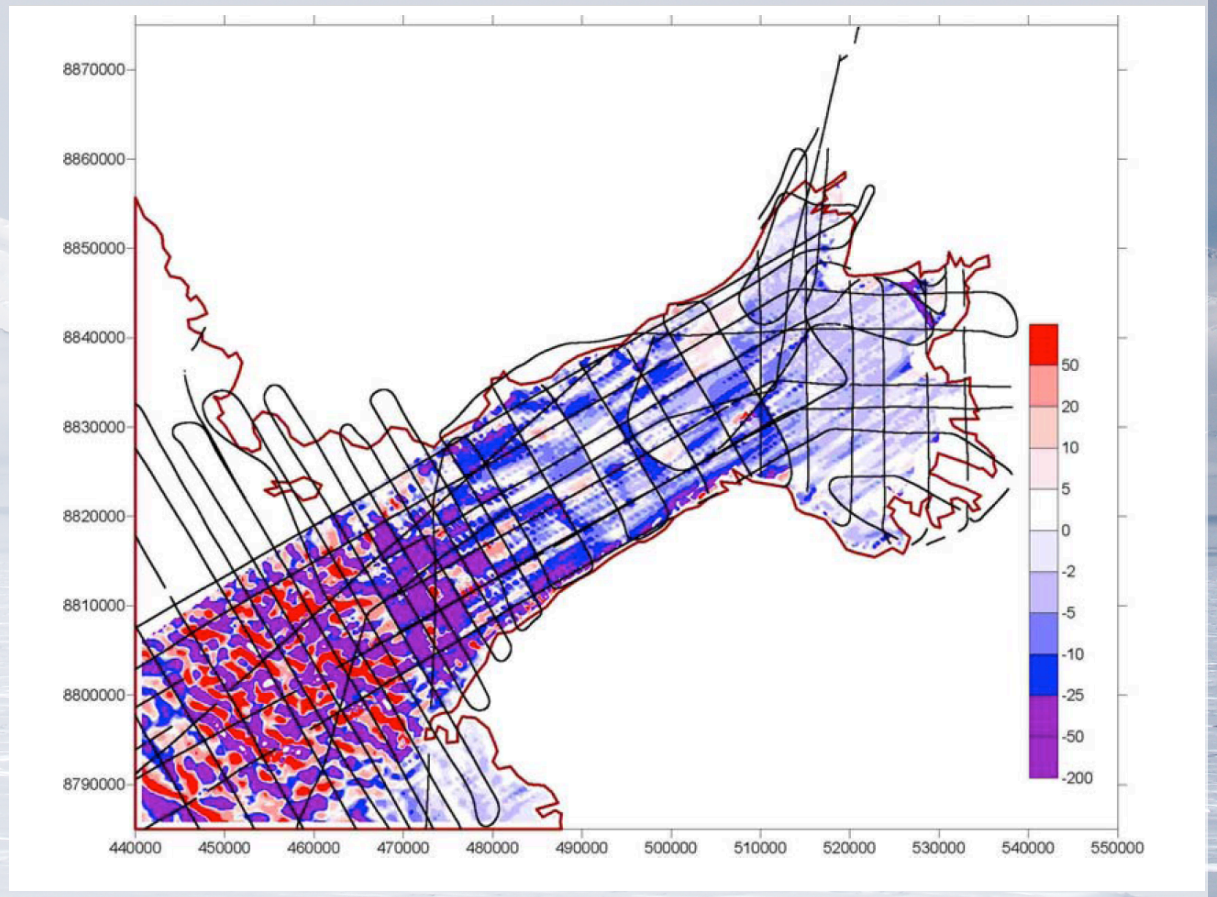
Flux divergence

Mass balance equation:

$$\frac{\partial H}{\partial t} = -\nabla \cdot (\bar{u} H) + \dot{M}_s - \dot{M}_b$$

H : thickness
ū : horizontal velocity
M_s : surface accumulation
M_b : basal melting

Flux divergence from ice thickness and InSAR velocities (m/yr)



N. Reeh, pers. comm., 2009

Motivations

- Mass balance equation

$$\frac{\partial H}{\partial t} = -\nabla \cdot (\bar{u} H) + \dot{M}_s - \dot{M}_b$$

➔ divergence term very noisy and not always physical

- Problem might come from:
  1. u_s (surface velocities) instead of $\bar{u}$ (depth-averaged velocities)
  2. resolution of H

- Here we investigate both effects on 79 North glacier

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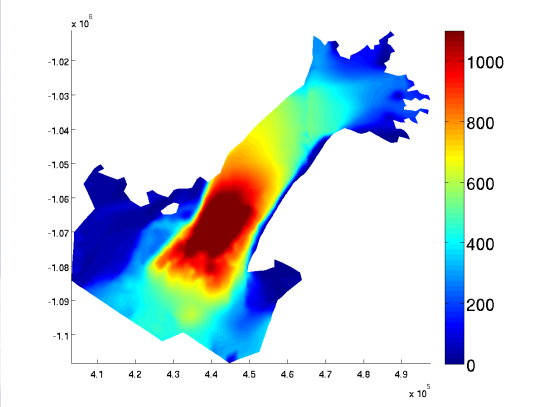
Experiment

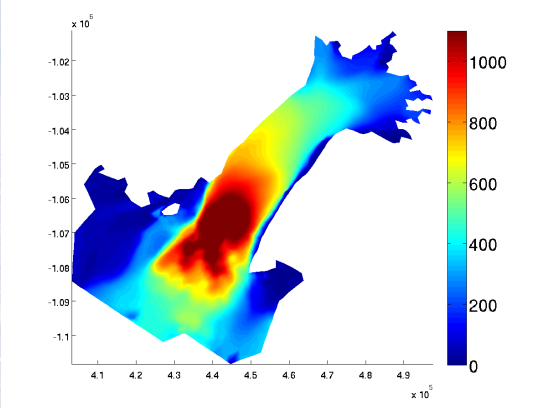
- Ice flow models
  - MacAyeal's shelfy stream [1989]
  - Pattyn/Blatter's higher order [2003]
  - Full Stokes
- Datasets
  - InSAR velocities from Rignot et al, 2001
  - Thickness/bed from Reeh, pers. comm., 2009
  - Surface temperature based on Huybrechts et al, 1993
- Data assimilation
  - Control method on ice rigidity on the ice shelf
  - Control method on basal drag on the ice sheet

Modeled vs observed velocities

Observed velocity [m/yr]

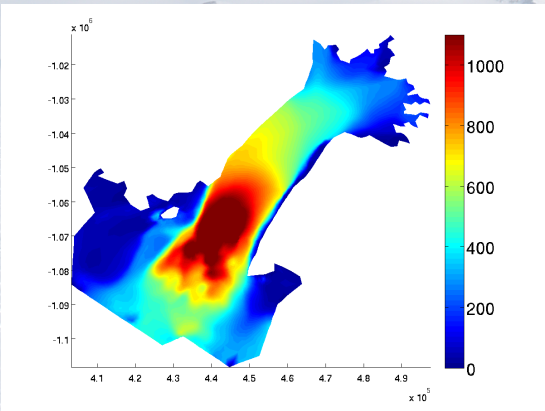


MacAyeal (SS) velocity [m/yr]



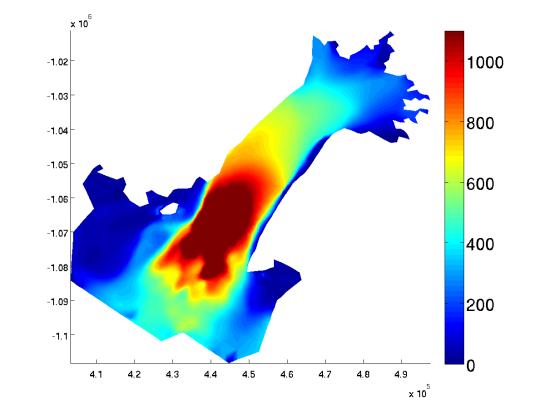
Average misfit: 25.3 m/yr

Pattyn (HO) velocity [m/yr]



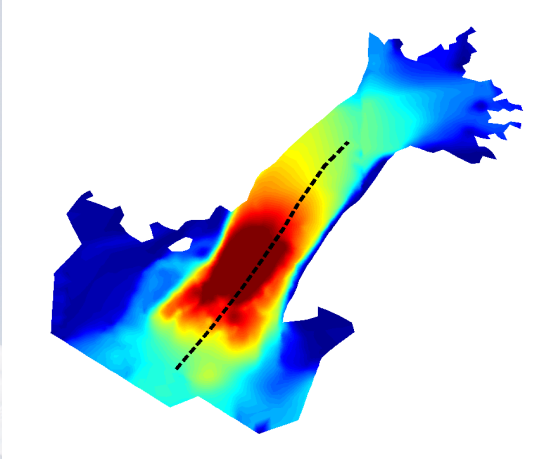
Average misfit: 24.6 m/yr

Stokes velocity [m/yr]

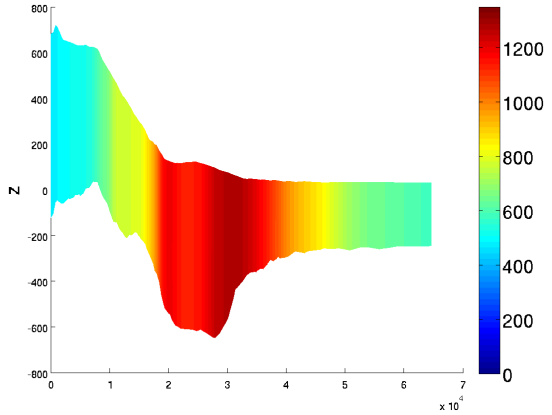


Average misfit: 22.1 m/yr

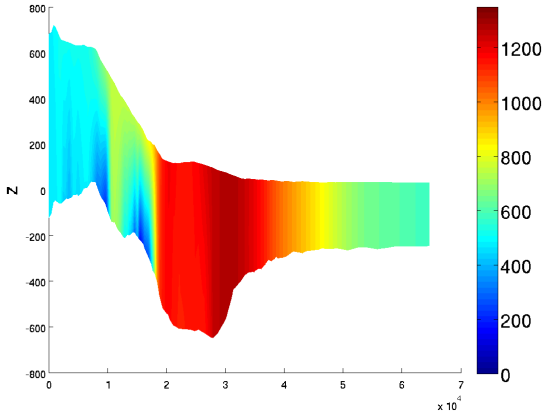
Cross sections velocities



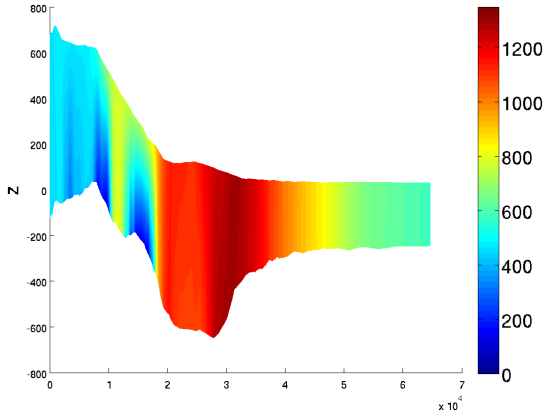
MacAyeal velocity [m/yr]



Pattyn velocity [m/yr]

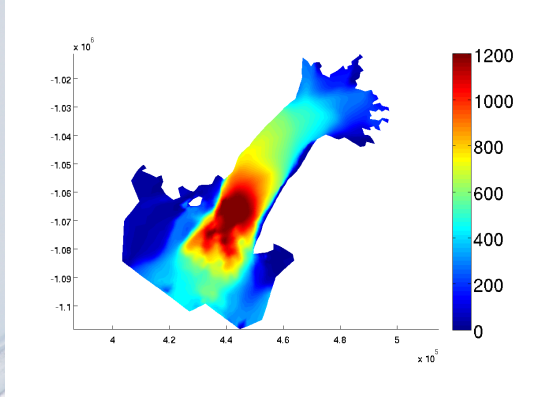


Stokes velocity [m/yr]

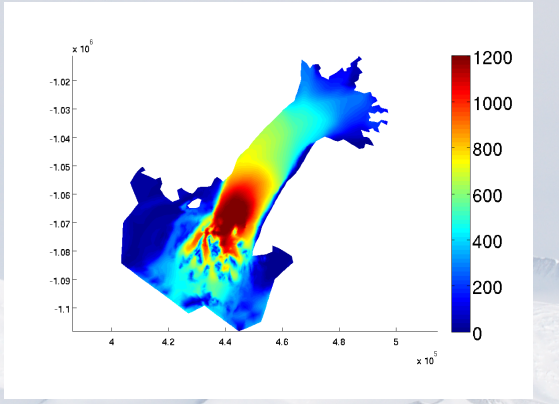


Depth dependence of velocity

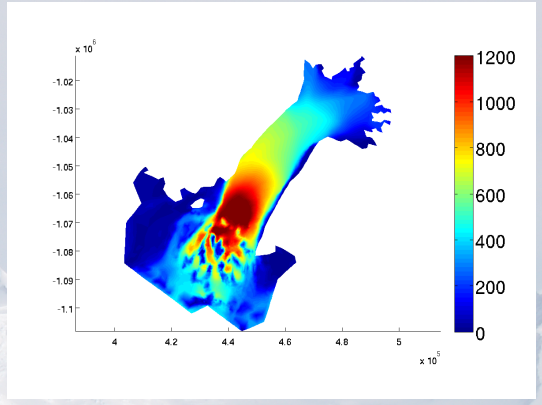
Basal velocity:



MacAyeal velocity [m/yr]

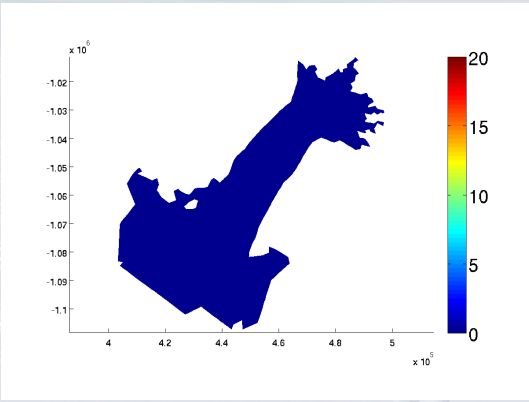


Pattyn velocity [m/yr]

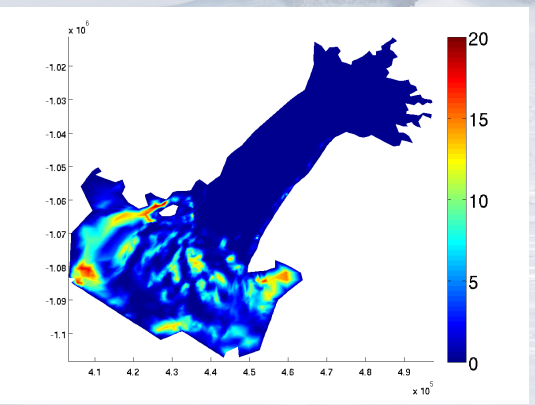


Stokes velocity [m/yr]

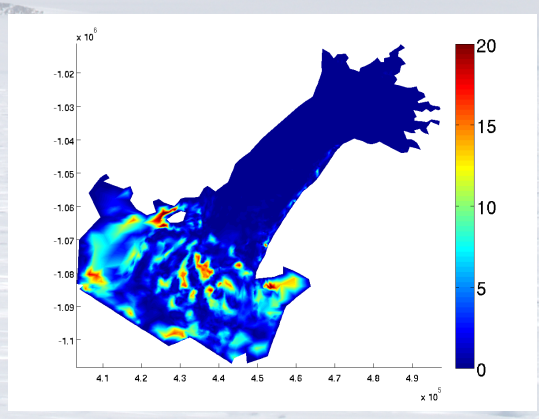
Relative difference between surface and average velocities:



MacAyeal difference [%]



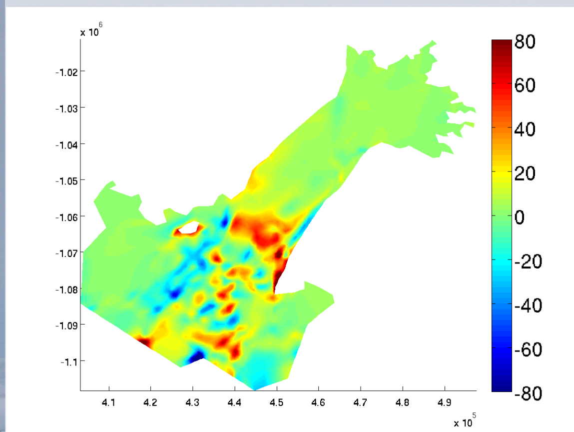
Pattyn difference [%]



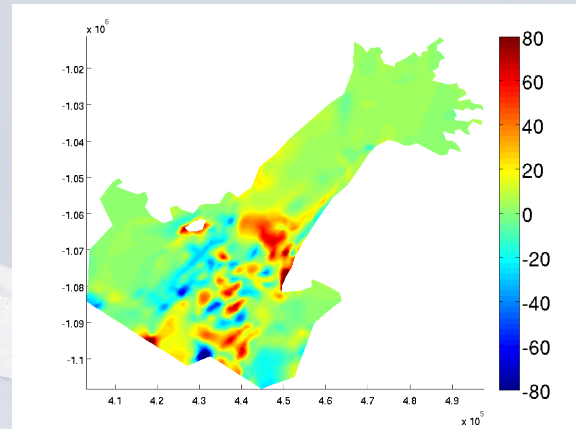
Stokes difference [%]

Flux divergence

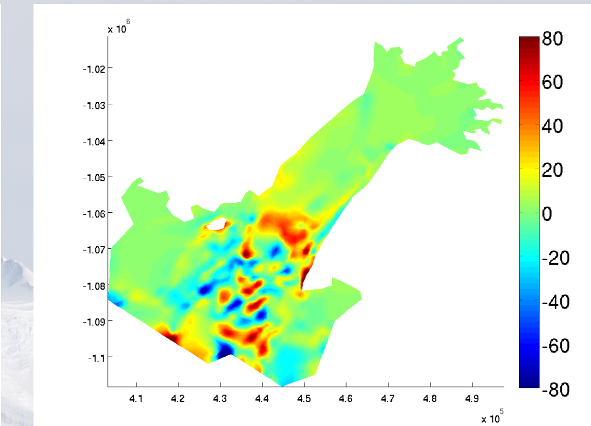
Flux divergence MacAyeal [m/yr]



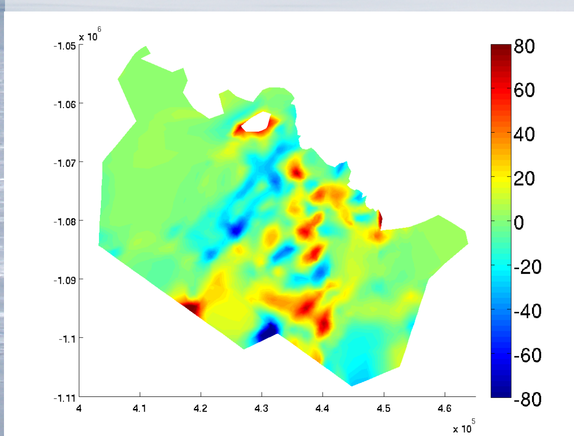
Flux divergence Pattyn [m/yr]

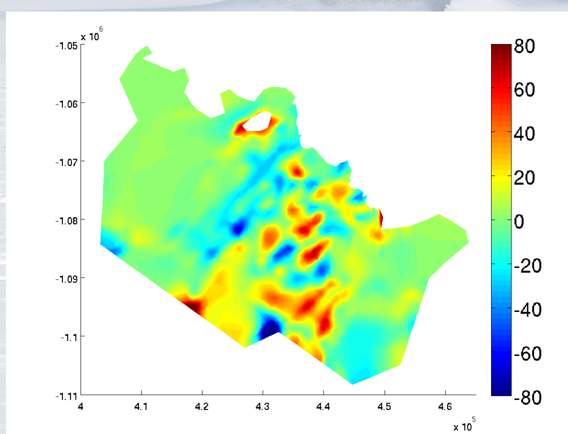


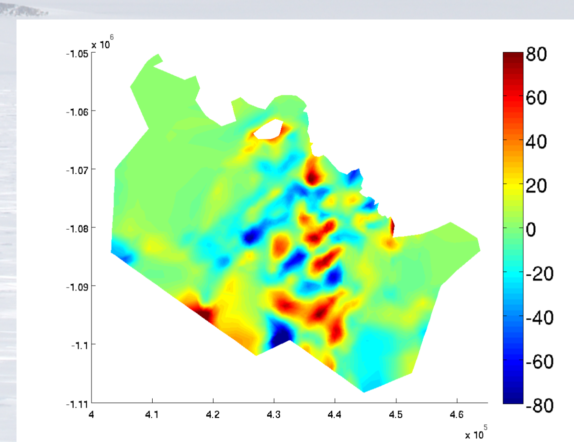
Flux divergence Stokes [m/yr]



Close-up on the ice sheet:







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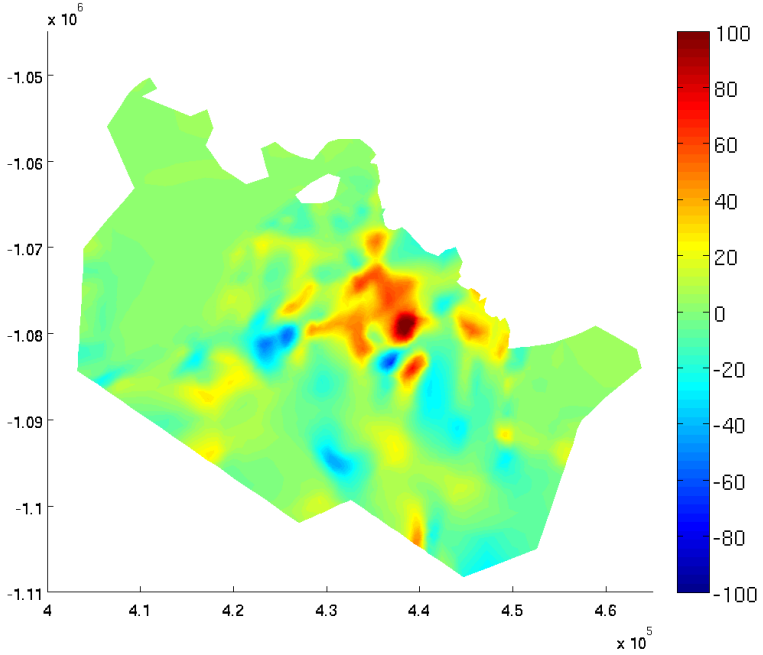
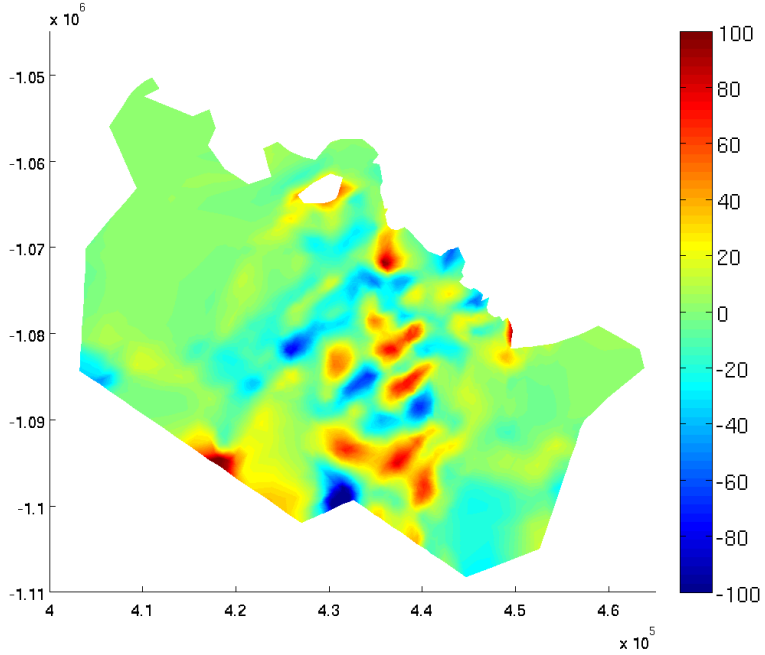
5 km vs 1 km resolution
Stokes velocities

- Is 1-km resolution sufficient ?
- Flux divergence with Stokes modeled velocity on two datasets

5 km resolution
(Bamber et al, 2001)

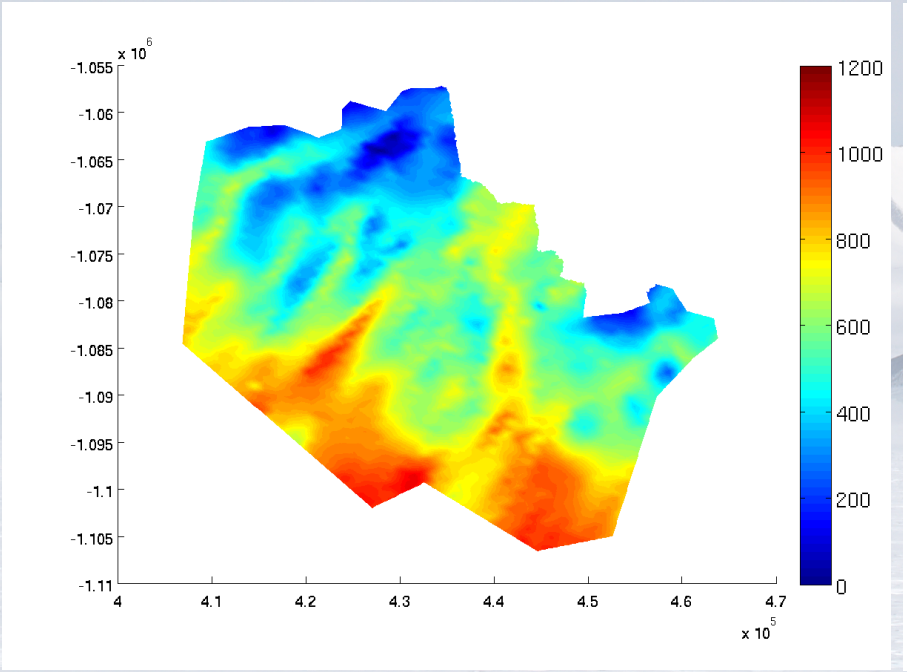


1 km resolution
(Reeh, pers. comm., 2009)

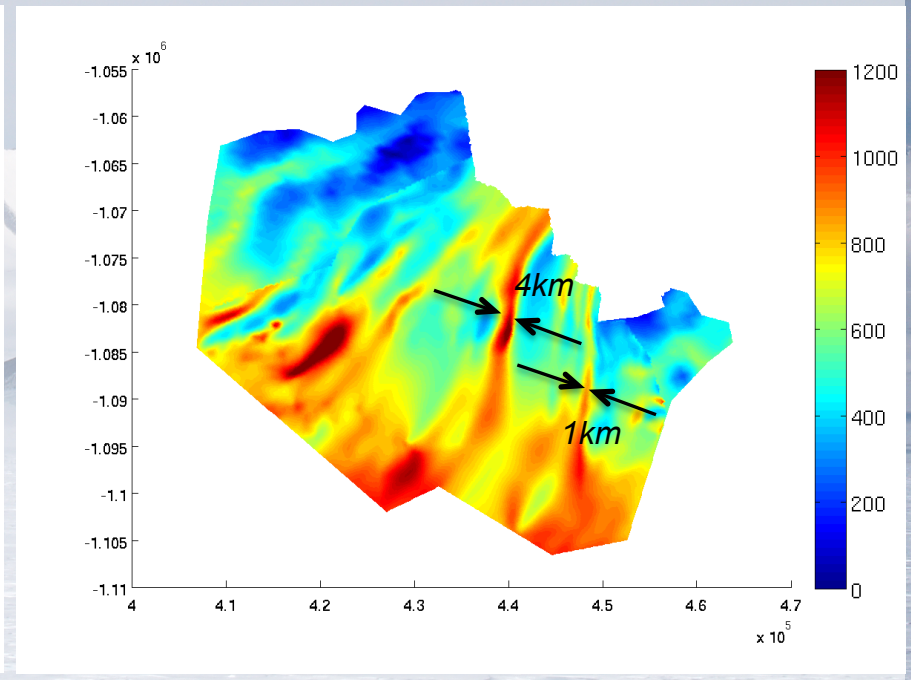


Balanced thickness

- Solve the thickness in the mass balance equation to have a steady-state and no accumulation/ablation: $\nabla(\bar{u}H) = 0$



1 km resolution thickness [m] (from 5 km-spaced tracks)



Calculated balanced thickness [m]

Conclusion

- Differences between surface and depth-average velocities are not sufficient to explain the calculated wiggles in flux divergence.
  ➔ It is not an effect of 3 dimensional flow over bumps.

- Pattern of melting/freezing sensitive to spatial resolution of thickness
  ➔ This means we need a higher resolution thickness data to obtain physically tenable flux divergence.

- What resolution do we need?
  ➔ Our inversion results suggest a spatial resolution of a few hundred meters

- Why do we need such high resolution data ?
  ➔ Ice flow significantly affected by the presence of bumps ~ thickness.
  ➔ Current maps may lead to erroneous results.

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